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HANA KAI II: HUMAN PHYSIOLOGY DURING A 17-DAY DRY SATURATION DI--ETC(U)

JUN 77 R M SMITH, S K HONG

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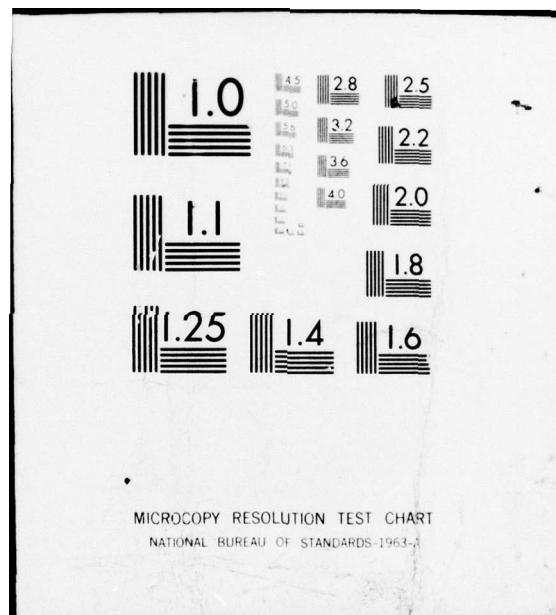
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## 19. KEY WORDS

Aegir  
 Hana Kai Dive  
 Heliox Saturation Dive  
 Bradycardia  
 Breath-holding  
 Face immersion  
 Pressure  
 Weight loss  
 metabolism  
 nitrogen balance  
 food intake  
 energy expenditure  
 oxygen consumption  
 carbon dioxide production  
 fecal losses  
 urine losses  
 body composition  
 convective heat transfer coefficient  
 aldosterone  
 antidiurectic hormone (ADH)  
 hyperbaric diuresis  
 insensible water loss  
 K balance  
 Na balance  
 prolactin  
 renin  
 total body water  
 water balance  
 impedance plethysmography  
 stroke volume  
 cardiac output  
 blood pressure  
 cold  
 thoracic blood volume  
 lung volumes and ventilation  
 maximal O<sub>2</sub> uptake  
 hyperoxic and normoxic helium breathing  
 work capacity  
 endurance time  
 cardiorespiratory responses to exercise  
 exercise bradycardia  
 maximal voluntary ventilation  
 audition  
 gustation  
 human performance  
 vision  
 cognitive performance  
 hyperbaric  
 narcosis  
 personality change  
 reaction time  
 subject selection  
 stress

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20. ABSTRACT

The present dive (Hana Kai II) was designed to carry out comprehensive studies on energy balance, body fluid balance, cardiorespiratory functions, maximal oxygen uptake, psychological performance and physiological responses to cold during a prolonged exposure to a dry heliox hyperbaric environment in man. The dive was carried out using Aegir to a depth of 580 ft (18.6 ATA) over a 30 day period in March-April 1975. Following a 3 day predive control at 1 ATA air (Period 1), 5 male divers spent 17 days at 18.6 ATA heliox environment (Periods 2-6), and returned to 1 ATA air after 7 days of decompression (Periods 7-8). They stayed an additional 3 days inside the chamber for postdive control measurements (Period 9). The chamber temperature was maintained at 25-27°C during Periods 1 and 9, 30-31°C during Periods 2-5, and 27-28°C during Period 6.

Final Report for Office of Naval Research

Hana Kai II: Human Physiology During a 17-Day

Dry Saturation Dive at 18.6 ATA.

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et al. (see list of publications)

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## ABSTRACT

The present dive (Hana Kai II) was designed to carry out comprehensive studies on energy balance, body fluid balance, cardiorespiratory functions, maximal oxygen uptake, psychological performance and physiological responses to cold during a prolonged exposure to a dry heliox hyperbaric environment in man. The dive was carried out using Aegir to a depth of 580 ft (18.6 ATA) over a 30 day period in March-April 1975. Following a 3 day predive control at 1 ATA air (Period 1), 5 male divers spent 17 days at 18.6 ATA heliox environment (Periods 2-6), and returned to 1 ATA air after 7 days of decompression (Periods 7-8). They stayed an additional 3 days inside the chamber for postdive control measurements (Period 9). The chamber temperature was maintained at 25-27°C during Periods 1 and 9, 30-31°C during Periods 2-5, and 27-28°C during Period 6. Environmental parameters, dive profile, designation of various experimental periods are described in detail. In addition, physical and physiological characteristics of individual subjects, the major daily activity schedule and the scope of investigation and collaboration are given.

Since previous saturation dives have caused loss of body weight despite apparently adequate to high food intake, a complete study of energy balance on 5 subjects was undertaken during the saturation dive called Hana Kai II. Over a 30-day period in the hyperbaric chamber all food, urine and feces for five men were analyzed by bomb calorimetry; 24-hr energy expenditure ( $M$ ) was measured from continuous  $\dot{V}O_2$ ,  $\dot{V}CO_2$ , and urine N; body weight was taken daily; body composition was assessed from density, total body water, and skinfold thickness. Food intake was high throughout the 30 days, about 3500 kcal/day, while fecal and urinary losses were a normal 6-8% of intake;  $M$  was increased a little by the hyperbaric condition, but averaged only 2431 kcal/day for

the 30 days, yet there was an average loss of adipose tissue of 0.8 kg. Nitrogen balance was positive. There was no evidence of heat gain or loss. The energy balance -- total fuel compared with energy expenditure -- required an additional 919 kcal/man-day for 30 days, an unidentified term which is not measured by conventional techniques.

Comprehensive studies on body fluid balance on 5 divers were conducted during the Hana Kai II dive. Daily urine flow increased from about 2,000 ml at 1 ATA to 2,600 ml at 18.6 ATA - 31°C. This diuresis was accompanied by a reduction in urine osmolality (from 650 to 500 mOsm) and a slight increase in osmolal clearance. Endogenous creatinine clearance remained at about 170 ml/min throughout the dive. Despite such a sustained diuresis, neither daily water intake nor total body water volume changed significantly. The plasma renin activity changed little, while both plasma aldosterone concentration and urinary aldosterone excretion increased significantly during the first week at 18.6 ATA. The plasma prolactin concentration showed a significant decrease during the first 3 days at 18.6 ATA. The daily excretion of antidiuretic hormone (ADH) decreased significantly (by 40%) 4 days after compression and remained low throughout the rest of the dive. Insensible water loss at 18.6 ATA was 35% lower than that at 1 ATA. It is suggested that the observed hyperbaric diuresis is due primarily to suppression of ADH as a result of suppression of insensible water loss.

Impedance plethysmography was used to measure resting cardiac stroke volume (SV) and thoracic conductive volume (TCV) in four divers at intervals during this prolonged dry saturation dive. Resting heart rate (HR), blood pressure (BP) and pulmonary minute ventilation ( $\dot{V}_E$ ) were measured 4 times per day for the duration of the 30 day experiment. The vital capacity (VC) and its subdivisions IC and ERV were measured by spirometry every 3 days.

VC in non-smokers fell significantly with time ( $r = .64$ ), while VC in smokers increased nearly 400 ml during the first week at pressure before tending to fall with time. Compared to predive, the mean ERV was increased 629 ml at pressure; while  $\dot{V}_E$  and respiratory rate were not changed. The increased ERV did not persist postdive and was probably the result of increased work of breathing a dense gas (4.1 gm/l). Residual volume (RV) measured by  $N_2$  dilution before and after the dive increased 38% and remained significantly increased (22%) even after one year in 4 divers. It is suggested that hyperoxia (0.3 ATA  $PO_2$ ) combined with increased gas flow resistance caused the VC to fall and RV to increase. The major resting cardiovascular findings were a transient bradycardia associated with increased stroke volume leading to a significant increase in resting cardiac output associated with an increased rate of rapid ventricular filling, TCV and BP at depth. Lowering the ambient temperature for 3 days did not re-establish the bradycardia, suggesting that hyperbaric bradycardia is not due to a subtle cold stress.

The heart rate (HR) responses to breath-holding (BH) with and without face immersion (FI) in 31° or 27°C water was studied in 1 ATA air and hyperbaric He- $O_2$  environments in 4 male subjects during the dive. When a 60 sec BH or FI was performed while leaning forward, there was a significant linear correlation between the maximal bradycardial response ( $\Delta HR_{max}$ ) and ambient pressure for simple BH ( $r = 0.80$ ,  $P < 0.05$ ) and 31°C FI ( $r = 0.91$ ,  $P < 0.01$ ), but not for 27°C FI. A similar trend was seen during 30 sec BH's while seated erect. The facial cold-dependent component of the FI bradycardia was not significantly altered by pressure. In general, there was significant correlations between the initial HR and the initial thoracic conductive volume (TCV; measured by the four electrode Minnesota impedance cardiograph), and between the initial TCV and  $\Delta HR_{max}$  observed during seated erect BH's. Since the

TCV was generally higher at depth, it is suggested that a mechanical effect due to increased TCV at depth, possibly related to increased gas density, is at least partly responsible for the pressure dependence of the resting BH bradycardia.

Cardiorespiratory responses of four men to submaximal and maximal cycling exercise were observed during the 17 days at 18.6 ATA. Inspired gas at pressure consisted of hyperoxic ( $P_{O_2} = 232$  mmHg) and normoxic ( $P_{O_2} = 159$  mmHg) helium mixtures with relative gas densities of 3.8 and 2.8, respectively. The average of pre- and post-dive  $\dot{V}_{O_2\max}$  (1 ATA air), which were not significantly different, was  $3.10 \text{ l}\cdot\text{min}^{-1}$ . During 5 min of submaximal exercise at 50% of  $\dot{V}_{O_2\max}$  no significant difference in work rate,  $\dot{V}_{O_2}$ ,  $\dot{V}_{CO_2}$ ,  $\dot{V}_E$ , respiratory rate, heart rate (HR), stroke volume, blood pressures, and rectal temperature was noted at 18.6 ATA with either gas mixture as compared to 1 ATA. Submaximal HR tended to decrease by 5 to  $10 \text{ b}\cdot\text{min}^{-1}$  at pressure and in hyperoxia the  $\dot{V}_{O_2}/\text{HR}$  ratio was significantly higher. Maximal exercise was performed to exhaustion at work rates requiring about 120% of  $\dot{V}_{O_2\max}$ . Significant increases in  $\dot{V}_{O_2\max}$  of  $0.10 \text{ l}\cdot\text{min}^{-1}$  (3%) and in endurance time of 2 min (48%) were found during hyperoxic gas breathing, whereas normoxic values at 18.6 ATA were similar to 1 ATA. Significant reductions in maximal HR of  $8 \text{ b}\cdot\text{min}^{-1}$  (4%) were observed with both gas mixtures at pressure and  $\dot{V}_E$  was significantly decreased by  $36 \text{ l}\cdot\text{min}^{-1}$  (26%) in hyperoxia and  $29 \text{ l}\cdot\text{min}^{-1}$  (21%) in normoxia. No change was found in the calculated impedance cardiac output. Maximal voluntary ventilation, which was measured only for the hyperoxic gas, fell significantly by  $80 \text{ l}\cdot\text{min}^{-1}$  (40%). The results indicate that aerobic power and endurance performance were affected by oxygen pressure. Normoxic work capacity, however, was not decreased at 18.6 ATA despite marked reductions in HR and  $\dot{V}_E$ .

Five divers were tested for alterations in auditory, visual and gustatory functioning during the 17-day saturation exposure to He-O<sub>2</sub> at 18.6 ATA. No evidence of permanent hearing loss was disclosed. Critical flicker fusion was not affected, but peripheral visual thresholds were significantly increased during the first two weeks at 18.6 ATA; this was interpreted as evidence of severe psychological and physiological stress. Foveal vision was unaffected across testings. Magnitude estimation techniques disclosed changes in taste sensitivity with sweet sensitivity increasing over time and sour sensitivity declining over the course of the dive. Subjects were more sensitive to bitter at maximum pressure than at sea-level, and less sensitive to salt at maximum pressure. The results indicate that appreciable alterations in sensory functioning can occur during saturation exposures, although the sense modalities were differentially affected by such environmental stressors as pressure, psycho-social stress, fatigue, and perceptual deprivation.

Measures of spatial orientation, associative memory, general intelligence, arithmetic ability, reaction time, and personal/social perceptions were administered to five subjects during the 30-day saturation exercise. Performance decrements were noted during 17 days of exposure to hyperbaric He-O<sub>2</sub> at 18.6 ATA. Significant losses in general intellectual ability were noted, as well as trends toward significant losses in other cognitive tests. Reaction time and arithmetic errors increased significantly during the early testing sessions. Performance during a 3-day cold period was equivocal; arithmetic errors increased, but other measures improved or remained constant. Environmental stressors such as fatigue, anxiety, health problems, personal and social adjustment, and aspects of perceptual deprivation were considered to be influential in reducing performance effectiveness.

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